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Abstract

Multiphase flow is frequently encountered in upstream O&G industry that has significant impact on the development of numerous production technologies such as multiphase flowmeter. Before the deployment of these technologies in an oil/gas field, the technologies are tested in a multiphase industrial flow loop test that emulates multiphase test conditions. This paper presents a digital twin of 2-phase flow (oil & water) as a low cost alternative to expensive multiphase flow test.

We have adopted backward strategy to design the digital twin of multiphase flow. At first, we characterized our proprietary microwave water-cut (WC) meter in an industrial flow loop in variable test conditions. Then, multiple digital models of the flow regimes were built and tested on our microwave WC meter. One of those models (rotated zigzag) was able to accurately predict WC sensor response over full WC range in oil continuous as well as water continuous flow conditions under varying salinity levels.

Two sets of responses have been recorded and compared – first obtained from the industrial flow loop trials and second from our EM simulation model. Key microwave resonator parameters such as resonant frequency (f_0) and quality (Q) factor have been compared under varying conditions. The comparison suggests that f_0 & Q-factor give higher sensitivity against WC in oil continuous and water continuous flow conditions respectively. Moreover, WC sensor performance was also compared under varying salinity conditions in the range of 20,000 ppm to 80,000 ppm and digital twin is able to successfully predict the sensor response in these conditions as well.

Significant amount of resources are spent on setting desired flow condition such as flow regime, WC and required salinity level. Our proposed digital twin model is able to emulate all of these multiphase flow conditions at negligible cost. It can help develop & test new production technologies without requiring to spend huge amount of money on lengthy, complex and expensive multiphase flow loop tests.

Introduction

Industrial flow loop is a controlled setup to emulate the flow conditions as close as possible to what is experienced in a real oil & gas field. For example, hydrocarbon liquids and gases along with saline water are being used in modern flow loop with pressures reaching close to actual production wells. As the multiphase fluid flow is affected by the operational parameters, it is therefore critical to validate new as well mature technologies in a flow loop environment before their deployment in the field.

One of promising uses of the flow loop facility is to emulate multiphase flow of oil, water and gas at adjustable flow rates and pressure conditions. Users can also adjust the salinity levels if the technology is known to be affected by it while temperature adjustment is also available in high-end flow loops. However, these tests can be quite costly (esp. at high pressure and variable temperature conditions) if they are to be performed for prolonged duration especially during calibration of the multiphase flow meters. On the other hand, fewer data points may result into poor calibration which eventually leads to the need of recalibration of the multiphase flow meters at regular intervals which itself is a huge operating expense (OPEX) for the end users.

This paper discusses a new technique to emulate multiphase flow conditions in an EM simulator. Using this technique, known as digital twin of the flow loop, designers can predict the response of new technologies to varying multiphase conditions without having to resort to expensive industrial flow loop tests. This technique has yet been tested with 2-phase (oil & water) conditions with varying water-cut over full range and covers oil continuous as well as water continuous regions. The technique successfully emulates the non-monotonic dielectric response of oil & water under varying salinity levels. The results obtained from the digital twin model have also been verified through measured data obtained from an actual industrial flow loop test.

Digital Twin model

Microwave DMOR is a Dual mutually orthogonal resonance technology, developed by the authors, to accurately measure the water-cut (WC) and gas volume fraction (GVF) in a multiphase flow [1, 2]. DMOR technology is essentially used for measuring the dielectric properties of multiphase mixture at low MHz microwave frequencies. Unlike other dielectric measurement technologies, DMOR resonance is a non-intrusive and orientation insensitive technology whose performance is unaffected by the orientation or mixing condition of the multiphase mixture. This paper puts DMOR technology under test to validate the digital twin modeling behavior of multiphase flow. The section below highlights the specifics about the technology.

Challenges in multiphase flow sensing and microwave DMOR technology:

Multiphase flow sensing can broadly be categorized in two categories based on whether it uses radioactive gamma rays or not. Gamma rays are typically employed to determine the gas void fraction (GVF) especially at high GVF conditions because gas has much less density than liquids. However, it has always been an active topic of research to measure multiphase flow without employing gamma ray source due to its associated health hazards as well as long regulatory procedures.

Microwaves are a good candidate to solve the multiphase sensing challenge without needing to rely on gamma rays. At the frequency of microwaves, it is possible to determine the complex (real and imaginary part) dielectric properties of multiphase mixture. Water has much higher dielectric constant than oil and gas while gas has much less dielectric loss compared to liquids (oil and water). Resultantly, a measurement mechanism (such as microwaves) exploiting both the dielectric constant and dielectric loss can differentiate between oil, water, and gases.

However, there are some inherent bottlenecks to quantify multiphase fluids based on microwave measurements only. It is because there are some additional factors such as temperature and salinity which may not only affect but can entirely alter the characteristic dielectric response of multiphase mixture. For example, salinity can have non-monotonic effect on the dielectric loss of brine which poses difficulty in its measurements unless it is characterized very well through industrial flow loop measurements. Moreover, it is also a known fact that some microwave sensors based on cavity resonator, lose their resonance in high salinity (lossy) conditions.

Microwave DMOR is essentially a microwave sensing technology (as shown in Figure 1) to measure the complex dielectric properties of multiphase mixture with some unique benefits. Firstly, the technology makes use of modified T-resonator (unlike cavity resonator) which excites proper quasi-TEM mode to give characteristic band-stop kind of response to the sensor even at extremely high salinities. That is why,

DMOR technology is known to work even in extremely high salinity levels (above 200,000 ppm). Secondly, the DMOR technology utilizes two mutually orthogonal resonators whose response if averaged, can give orientation insensitive measurements. This feature allows the sensor to be mounted in any orientation (horizontal, vertical or any angle in between) and is minimally affected by the mixing conditions of the multiphase mixture. Moreover, the DMOR technology has been put under test of digital twin model of industrial flow loop in this paper. It means that we can characterize this technology very well in variable temperature and salinity conditions to be able to generate AI based lookup tables which can potentially solve for the unknown phase fraction of multiphase mixture. It must be noted here industrial flow loop is a complicated and expensive test setup and the number of test points required to properly characterize a microwave-only sensor is quite challenging which has been replaced by our digital twin model of industrial flow loop model as presented in this paper.

Figure 1. "Dual mutually orthogonal resonator" based WC sensor design operating in low microwave frequency band

One of the important factors in multiphase measurements is the phase continuity. If the small water particles are dispersed inside oil, it is known as oil continuous flow while water continuous flow refers to a fluid condition in which oil particles are dispersed in water. The phase continuity affects the dielectric properties of the multiphase mixture which is why it is quite important to emulate these conditions in our digital twin model. Figure 2 shows a dummy illustration of water-continuous flow in which water blankets oil particles and it forms a continuous path from one end of the sensor to the other. It can be seen from Figure 2 that electric fields find a low resistance (conductive) path from resonator signal to resonator ground plane. Irrespective of oil percentage in water continuous flow conditions, propagation speed and hence the resonance frequency of the microwave resonator stays almost the same.

Figure 2. Dummy illustration of water blanketing effect in water continuous region

In consideration of the continuity concept, we pixelated the fluid volume such that we are able to precisely set the water fraction in oil commonly known as water-cut (WC). Additionally, the salinity levels can also be set precisely in the form of dielectric loss of water. This paper covers the salinity levels from 25,000 ppm to 200,000 ppm and WC in water continuous regime from 50% to 100%. After trying different models, criss cross zig zag pattern (as shown in Figure 3) was found to emulate water-continuous conditions very precisely. This model was verified by comparing the simulation results from industrial flow loop data, obtained from NORCE flow loop based in Norway.

Figure 3. Criss Cross zig zag model to emulate water-continuous flow conditions

Microwave resonators have two key parameters i.e. f_0 and Q-factor to measure their dielectric properties. Using the model shown in Figure 3, simulation data were obtained which was then compared with the measured data from the flow loop. Figure 4 shows the comparison of simulated and measured resonance frequency (f_0).

Figure 4. Comparison of (a) measurement and (b) simulation data of resonance frequency (f_0) of microwave DMOR sensor

It can be seen from Figure 4 that simulation model is able to predict the non-monotonic dielectric response of the multiphase fluid over wide WC range and varying salinity levels. At low salinity levels (1.92 %), f_0 decreases by increasing WC while it stays relatively flat at medium salinity levels (4 %). When we increase the salinity beyond 4%, f_0 flips its response and its values increases with the increase in WC. This behavior has been accurately modeled in our digital twin simulation model as evident from above comparison.

Similarly, Q-factor is linked to dielectric loss of the multiphase mixture and the comparison of measured and simulation data is shown in Figure 5.

Figure 5. Comparison of (a) measurement and (b) simulation data of Quality (Q) factor of microwave DMOR sensor

It can be seen from Figure 5 that measured data (a) correlates well with the digital twin simulation model (b). The non-monotonic response of Q-factor with changing salinity levels has been predicted well by our model. At low salinity level (1.92%), Q-factor increases with increasing WC and it become relatively flat at medium salinity levels (4%). On the other hand, Q-factor starts to decrease with increasing WC at high salinity levels (>6.55%).

After validating the simulation model through its comparison with the measured flow loop data, we have run the model on additional test points which were impossible to achieve in the flow loop. For example, we have tested our model at a very high level of salinity of 18.5% as can be seen from Figure 5 (b) and it can be confirmed that the microwave DMOR sensor operates well even at extreme operating

conditions.

Conclusion

The paper presents a novel way to emulate flow loop conditions in a simulation model in order to predict accurate dielectric properties of multiphase fluid. The model has been tested to emulate water-continuous flow condition with the capability to independently adjust the WC & salinity levels. With the use of this model, technologists can digitally predict the dielectric properties of the multiphase mixture which can help develop new technologies at a fraction of cost.

References

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